Effects of mental fatigue on 8-13Hz brain activity in people with spinal cord injury

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Abstract— Brain computer interfaces (BCIs) can be implemented into assistive technologies to provide 'hands-free' control for the severely disabled. BCIs utilise voluntary changes in one's brain activity as a control mechanism to control devices in the person's immediate environment. Performance of BCIs could be adversely affected by negative physiological conditions such as fatigue and altered electrophysiology commonly seen in spinal cord injury (SCI). This study examined the effects of mental fatigue from an increase in cognitive demand on the brain activity of those with SCI. Results show a trend of increased alpha (8-13Hz) activity in able-bodied controls after completing a set of cognitive tasks. Conversely, the SCI group showed a decrease in alpha activity due to mental fatigue. Results suggest that the brain activity of SCI persons are altered in its mechanism to adjust to mental fatigue. These altered brain conditions need to be addressed when using BCIs in clinical populations such as SCI. The findings have implications for the improvement of BCI technology.

I. Introduction

A severe disability such as spinal cord injury (SCI) result in loss of sensory and motor function below the level of injury, leaving patients dependent on their carers. Assistive technology such as environmental control systems (ECSs) are designed to provide some independence for disabled people through providing 'hands-free' control over their environment. Brain computer interfaces (BCIs) include technology that utilises voluntary changes in one's brain activity [1]. BCIs are particularly useful to those who suffer from severe disability such as tetraplegia (damage to the spinal cord at neck level). These people have no or very limited movement below the neck, and with the aid of BCIs they can be trained to use their brain activity to operate effectively and reliably devices such as computers, televisions and other assistive technology [2][3]. Brain activity is commonly measured by electroencephalography (EEG), which records cortical postsynaptic electrode potentials that can be categorized into four major bands based on their frequency: delta (0.5-3.5), theta (4-7.5Hz), alpha (8-13Hz), and beta rhythms (14-32Hz). Craig et al. [4] has successfully demonstrated the ability of changes in 8-13 Hz brain activity associated with eye closure to be used as a 'switch' in BCIs. During eye closure, there is a significant increase in alpha or 8-13Hz activity, which is believed to be due to reduction in visual input [4]. This alpha wave increase with eye closure can be seen in most people, and has been shown to be reliable and quick enough to be used as a switching mechanism, in both able-bodied and people with disabilities [4][5].

However, previous studies have found a decrease in 8-13Hz activity in those with SCI, particularly in those who are tetraplegic [6]. It is expected that these people may have experienced some alteration in their brain activity that could be associated with deafferentation of nerve pathways [6]. Another common problem associated with SCI is fatigue and psychological distress [7][8], which can also affect brain activity. Fatigue has been shown to be associated with changes in EEG and is known to affect a person's alertness and concentration [9][10]. Activation and use of BCIs would require a great deal of concentration and mental demand and could be expected to cause fatigue in the user. This could pose a challenge in a population such as those with SCI, who experience fatigue and psychological distress on a daily basis. It is therefore important to study the effects of increased cognitive demand and fatigue on the brain activity of those with SCI in order to know whether these changes may compromise the efficacy of BCIs.

The present study examined changes in brain activity in a group of able-bodied controls and those with SCI after completing a set of cognitive tasks. The participants completed a set of cognitive tasks that were designed to increase levels of cognitive demand [11]. Increased cognitive demand is expected to cause mental fatigue [12]. Changes in 8-13Hz activity from eyes open and eyes closed conditions before and after the cognitive task were examined, and comparisons were made between able-bodied controls and SCI participants.

II. Methods

A. Participants

Ten able-bodied controls (mean age=40) and ten SCI participants (mean age=51.7) were entered into the study after informed consent. The SCI group consisted of both paraplegic (n=6) and tetraplegic (n=4) participants. Control participants were screened for prior head injuries and neurological disorders. Participants were asked to refrain from consuming alcohol for 12 hours and caffeinated

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beverages for 2 hours prior to the study.

B. Data acquisition and Study protocol

EEG data was acquired using a Neuroscan data acquisition system, and participants wore a Quick cap™ that recorded brain activity over 20 cortical sites (Figure 1). Data was acquired at a sampling rate of 500Hz with reference to Virtual ground.

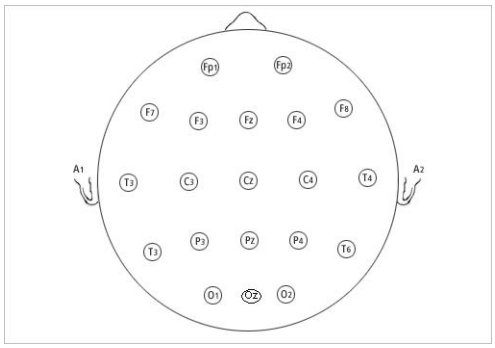

Fig. 1. 10-20 system of electrode placement

EEG activity was acquired while participants had their eyes open (EO 1) and eyes closed (EC 1) and was recorded at the beginning of the study. Both EO 1 and EC 1 sessions were of 30 seconds duration each. After the first EO/EC session, participants completed a set of cognitive tasks. These tests were administrated according to the Brain Resource Company (BRC) international standards [13]. The tests were presented in such an order that they increased in complexity and cognitive demand [11], and the tests took approximately 50-60 minutes to complete. In order to record any changes in brain activity following the cognitive tests, a second set of EO/EC activity was recorded immediately after participants completed the task. Similar to the first EO/EC session, this session also consisted of eyes open (EO 2) and eyes closed (EC 2) sessions of 30 seconds each.

C. Pre-processing and Spectral analysis

EEG data were re-referenced to ears and re-sampled to 250Hz before spectral analysis. Data was spectrally analysed using Fast Fourier Transformation (FFT), and the power (dB) of 8-13Hz frequency (alpha) band was calculated.

III. Results

Independent t-test results of the EC 2 data showed that there are significant differences in alpha activity between able-bodied controls and SCI at O1 (p= 0.037) and Oz (p=0.023) occipital sites. These results indicate that the control group had significantly greater alpha activity compared to the SCI group. In addition to O1 and Oz, the following sites achieved a near significance: Fz (p=0.076), F4 (p=0.079), FC3 (p=0.069), FCz (p=0.074), FC4 (p=0.073), C3 (p=0.074), Cz (p=0.073), T6 (p=0.055) and O2 (p=0.052).

Effect sizes were calculated to test the strength of the differences in alpha activity between the two groups reported during EC 2 session. The effect size for most of these sites exceeded 0.4 (0.6 to 0.9) (see Table 1), thereby indicating a reasonable difference in brain activity between the two groups. T-tests found no significant differences between the two groups in the EO1, EC1, and EO2 sessions.

Repeated measures ANOVA analysis was carried out to test for differences in EEG activity before and after participants completed the set of cognitive tasks. Repeated measures ANOVA did not find any significant differences between groups, based on session; however, the graphs showed clear changes in alpha activity following cognitive tasks in several sites. In general, there was an increase in alpha activity in the control group during EC 2, particularly in frontal sites. In contrast, the SCI group showed a decrease in alpha activity, particularly in occipital and parietal sites. Figures 2, 3, 4 and 5 shows the ANOVA results for Fz ($F(4,15)=1.5916$, $p=0.227$), Cz ($F(4,15)=1.5916$, $p=0.227$), Pz ($F(4,15)=1.5916$, $p=0.227$ and Oz ($F(4,15)=1.5916$, $p=0.227$) sites respectively.

TABLE I
EFFECT SIZES FOR GROUP DIFFERENCES IN ALPHA ACTIVITY DURING EC2

Site	Mean		Std. deviation		Effect
	Control	SCI	Control	SCI	size
FP1	36.022	33.189	4.207	3.696	0.717
FP2	36.285	33.514	3.954	3.498	0.744
F7	35.419	33.436	4.078	3.332	0.535
F3	35.399	32.386	4.390	3.709	0.744
Fz	35.948	32.649	3.944	3.891	0.842
F4	35.419	32.146	3.849	4.031	0.831
F8	35.537	33.506	3.646	2.804	0.630
FC3	34.725	31.529	4.134	3.226	0.868
FCz	35.388	32.310	3.680	3.586	0.847
FC4	34.504	31.360	3.683	3.691	0.853
T3	34.698	33.973	3.601	2.940	0.222
C3	33.873	30.808	4.171	2.964	0.859
Cz	33.904	31.021	3.482	3.295	0.851
C4	33.247	30.779	3.984	3.817	0.633
T4	34.779	34.275	3.490	3.110	0.153
CP3	33.906	31.603	4.558	2.864	0.620
CPz	34.473	31.695	4.519	3.135	0.726
CP4	34.159	31.877	4.829	3.980	0.518
T5	38.500	35.613	4.305	3.520	0.738
P3	36.412	33.368	5.041	3.153	0.743
Pz	37.352	33.647	5.379	4.059	0.785
P4	37.142	33.726	5.333	3.769	0.751
T6	41.320	37.277	4.655	4.140	0.919
O1	41.632	37.207	4.516	4.247	1.010
Oz	40.570	36.245	3.680	4.267	1.089
O2	41.424	37.475	4.264	4.226	0.930

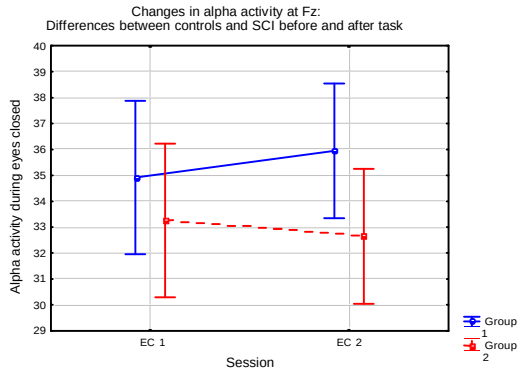

Fig 2: Shows the changes in the alpha spectra at Fz site during EC 1 and EC 2 (Group1= Controls, Group 2= SCI)

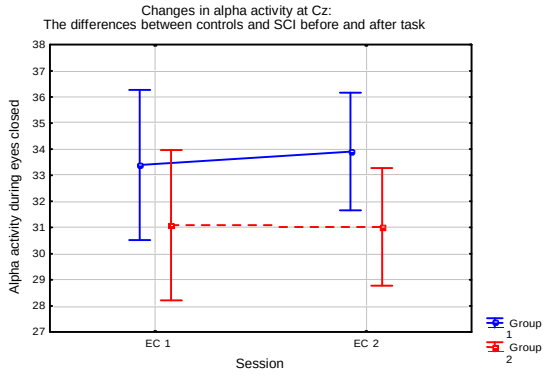

Fig 3: Shows the changes in the alpha spectra at Cz site during EC 1 and EC 2 (Group1= Controls, Group 2= SCI)

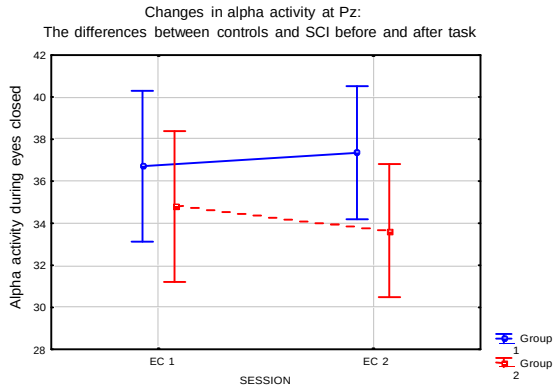

Fig 4: Shows the changes in the alpha spectra at Pz site during EC 1 and EC 2 (Group1= Controls, Group 2= SCI)

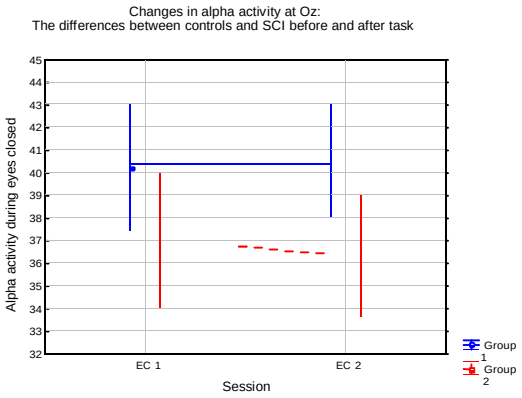

Fig 5: Shows the changes in the alpha spectra at Oz site during EC 1 and EC 2 (Group1= Controls, Group 2= SCI)

IV. Discussion

T-test results showed significant differences in EEG activity at O1 and Oz sites during the second EC session (EC 2) between the able bodied and SCI subjects. The results suggested that the SCI group had lower levels of alpha activity in the occipital region compared to able-bodied controls during a fatiguing condition. Though the other sites did not report statistical significance, several sites, particularly in the frontal area of the head (see Results), reported near significance. This finding is of substance when sample size is considered. Both control and SCI groups consisted of ten participants, and a higher significance rate could be expected if the study was repeated with a larger number of participants. This is further evident by the moderately large effect sizes reported for all sites during EC 2 (see Table 1). In terms of mean values, the control group reported a higher alpha activity at all cortical sites recorded. The effect size for most of these sites ranged between 0.6-0.9, which implies a reasonable difference in brain activity between the two groups. This decrease in alpha activity in SCI is consistent with the literature. For instance, Tran and colleagues [6] found a consistent decrease in 8-13Hz activity across the scalp in SCI participants compared to able-bodied controls. No statistically significant differences in EEG activity were observed during EC 1. Based on the literature, a reduction in alpha activity in the SCI group compared to controls was expected during both sessions, but the lack of such a finding was very likely a result of the small sample number studied in this study.

Repeated measures ANOVA results were not statistically significant. Nevertheless, they showed changes in alpha activity in both control and SCI groups, following the set of cognitive tasks (Figures 2-5). Interestingly, the two groups showed a change in alpha activity in opposite directions, suggesting a difference in the SCI and able bodied responses to mental fatigue. Alpha activity increased in the control group after completing the cognitive tasks, whereas alpha activity decreased in the SCI group. Increase in alpha activity generally indicates a relaxed state of mind [14]. The

increased alpha activity in the control group suggests that when people with no neurological damage experience mental load, they more likely respond by demonstrating a more relaxed or idle neural state. Conversely, SCI participants did not appear to show the same response. This could also explain the higher incidence of fatigue in the SCI population [15]. The differences in brain activity in SCI could be associated with the reorganisation of the brain following the injury. There is evidence to suggest that SCI results in certain changes in the brain including organisational and chemical alterations [16] [17]. These changes could affect the 8-13 Hz activity in SCI. Furthermore, the literature suggests that SCI could be associated with deficits in cognitive function [18][19]. Alpha activity is positively related to cognitive function such as memory performance [20] and the deficits found in cognitive performance could also contribute to increased mental fatigue in the SCI group.

Regardless of the cause, these changes in brain activity could affect the performance of BCIs. The lowered 8-13Hz activity, coupled with negative effects of fatigue and increased cognitive demand can compromise the efficacy of BCIs. The results need to be re-tested with a larger sample size to provide a more clarified understanding of the changes in brain activity. However, these findings do have implications for the improvement of assistive technology.

V. Conclusion

Mental fatigue and increased cognitive demand affected the alpha spectral activity in both control and SCI groups. The able-bodied brain appears to cope with mental demand by shifting to a more relaxed or idle state that was indicated by an increased alpha activity. In contrast, alpha activity was reduced or remained unchanged in the SCI group, suggesting that the SCI brain may lack the resources to cope with demanding cognitive tasks compared to able-bodied persons. The reliability and efficiency of BCI technology would depend upon the consistency of the brain activity of its user. Therefore, any inconsistency in brain activity as observed in the study would need to be further investigated, as these changes may well adversely affect the performance of BCIs. The negative effects that may occur as a result of these altered brain conditions in SCI need to be addressed when designing BCIs for people with similar disabilities.

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